PB89-136618

Pathogen/Vector Attraction Reduction in Sewage Sludge Technical Support Document

(U.S.) Environmental Protection Agency
Washington, DC

1988

U.S. Department of Commerce
National Technical Information Service
NTIS

PB89-136618

United States
Environmental Protection
Agency

Office of Water
Regulations and Standards
Washington, DC 20460

EPA

Water

TECHNICAL SUPPORT DOCUMENT

Pathogen/Vector Attraction Reduction in Sewage Sludge

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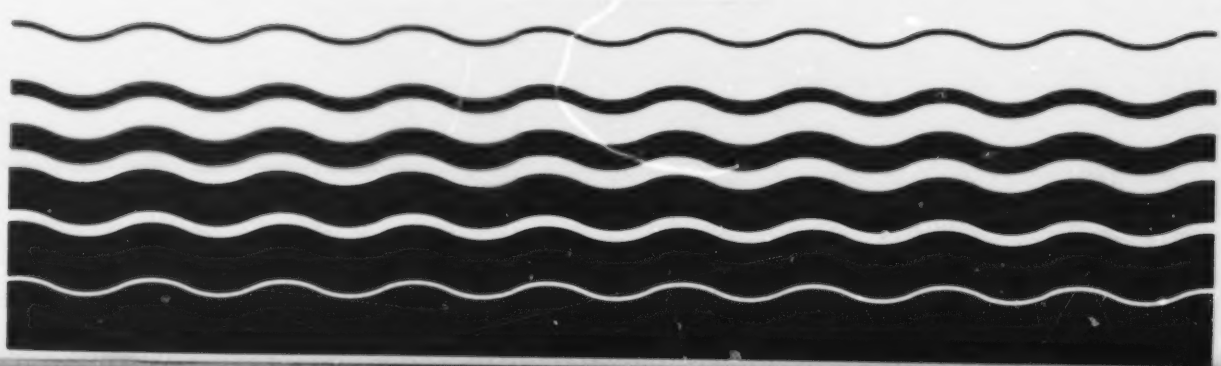

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO.	2.	3. Recipient's Accession No. PB89-136618AS
4. Title and Subtitle: Technical Support Document Pathogen/Vector Attraction Reduction in Sewage Sludge			5. Report Date
			6.
7. Author(s): U.S. Environmental Protection Agency, Office of Water Regulations and Standards			8. Performing Organization Rept. No.
9. Performing Organization Name and Address: U.S. Environmental Protection Agency, Office of Water Regulations and Standards, 401 M Street, SW, Washington, DC 20460			10. Project/Task/Work Unit No.
			11. Contract(C) or Grant(G) No. (C) (G)
12. Sponsoring Organization Name and Address: U.S. Environmental Protection Agency, Office of Water Regulations and Standards, 401 M Street, SW, Washington, DC 20460			13. Type of Report & Period Covered
			14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This document provides the technical background and justification for the U.S. Environmental Protection Agency's (EPA's) proposed regulation (40 CFR Part 503) on pathogen and vector attraction reduction in municipal wastewater sludge (Subpart F). The document summarizes the existing 40 CFR 257 Federal regulations for controlling pathogens and vector attraction in sludge and discusses their shortcomings. It presents the components of disease risk, including the pathogens of concern (bacteria, viruses, protozoa, and helminths), their types, measurement, environmental fate and transport, and infective dose. The document discusses the principal aspects of the proposed new regulations concerning sludge pathogen and vector attraction control and discusses the available scientific information that supports these regulations, as well as data gaps and areas where additional information would be helpful.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
To Be Released To The Public		63
	20. Security Class (This Page)	22. Price A04

(See ANSI-Z39.18) See Instructions on Reverse

OPTIONAL FORM 272 (4-77) (Formerly NTIS-35) Department of Commerce

PREFACE

Section 405(d) of the Clean Water Act requires the U.S. Environmental Protection Agency (EPA) to develop and issue regulations that identify:

- Uses for sludge, including various means of disposal
- Factors, including costs, which must be considered when determining the measures and practices applicable to each use or disposal method
- Pollutant concentrations that interfere with each use or disposal method

To comply with this statutory mandate, EPA has embarked on a program to develop five major technical regulations: land application, distribution and marketing; monofilling; surface disposal; incineration; and reduction of pathogens and vector attraction. EPA has also proposed regulations governing the establishment of State sludge management programs, which will implement both existing and future criteria (40 CFR 501).

The principal goal of the proposed regulation for pathogen and vector attraction reduction is to protect human health. These requirements apply to sewage sludge that is applied to the land, distributed and marketed, or placed in a monofill or impoundment. This document provides the technical background and justification for the provisions contained in Subpart F of the proposed regulation.

Public comment on the technical adequacy and scientific validity of this document as well as the requirements contained in the proposed regulation should be submitted during the public comment period. Any questions related to this document may be directed to:

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LIST OF UNITS AND ACRONYMS

CFU	colony-forming units
cm	centimeter
EPA	U.S. Environmental Protection Agency
g	gram
ha	hectare
m	meter
mg	milligram
mL	milliliter
mm	millimeter
MPN	most probable number
NP/LSA	no primary/long-sludge age
no./g VSS	number pathogens/gram volatile suspended solids sludge
PFRP	process to further reduce pathogens
PFU	plaque-forming units
PSRP	process to significantly reduce pathogens
VS	volatile solids
VSS	volatile suspended solids

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SECTION ONE

INTRODUCTION

Human bodily waste has been applied to soil for its fertilizer value and organic content since the beginning of recorded history and, no doubt, before that time. Land application of human wastes has many beneficial aspects; however, most countries of the world now regulate this practice to minimize the potential for the spread of disease by pathogens (disease-causing microorganisms) in human wastes and the possibility that contaminants in sludge may reduce soil productivity and crop wholesomeness.

This technical support document describes sludge utilization in the United States and the risks of disease from sludge utilization. It summarizes the existing Federal regulations for controlling pathogens in sludge, discusses their shortcomings, and presents new knowledge relevant to creating an improved regulation. Section 3 presents the principal aspects of the proposed new regulations concerning sludge pathogen control and discusses the available scientific information that supports these regulations, as well as data gaps and areas in which additional information would be helpful.

1.1 SLUDGE USE ON LAND BEFORE FEDERAL REGULATION

Most cities and towns in the United States have processed their wastewater in centralized facilities since the early 1900s. This processing produced large volumes of sludge that had to be disposed of. Widely disparate disposal practices developed, ranging from ocean disposal to incineration; each municipality chose the practice that best suited its particular circumstances. Frequently, muncipalities simply gave their sludge away to farmers or processed it into a fertilizer product.

Agricultural use of sludge was important enough that, in 1946, members of the Federation of Sewage Works Associations (the forerunner of the Water Pollution Control Federation) made it the subject of their second manual of practice: "Utilization of Sewage Sludge as Fertilizer" (FSWA, 1946). Their manual details a variety of utilization practices in use at that time. Several large municipalities were heat drying waste-activated sludge and selling it as a fertilizer. Air-dried digested sludge, generally dried on sand beds, was used on orchards. The manual recommended using the material in the same manner as manure for vegetable crops, including root crops. It also described use of municipal sludge on farms growing oats and wheat, and tank truck delivery of sludge for use on lawns and parks. The manual cautions about pathogenic organisms in sludge, but notes that only 1 of 33 states that responded to a survey had regulations to protect public health from this potential threat.

Although the manual indicates some awareness of the potential health hazard from sludge use (for example, the manual recommends that raw primary sludge not be used on the land), the land application practices in use at that time were not uniform and, in some cases, apparently posed a high risk to health. Burd (1968) listed similar uses of sludge in the late 1960s and noted that the hygienic considerations relating to sludge use were primarily under the authority of local health boards.

The 1972 Federal Water Pollution Control Act (PL 92-500) encouraged land application of sludge by explicitly endorsing nutrient recycling and by stimulating construction of wastewater treatment facilities. Large cities became interested in land application. Chicago developed its "Prairie Plan" for agricultural use of most of its sludge (Dalton and Murphy, 1973). The great interest in and diverse approaches being suggested for land application of sludge necessitated strong guidance to protect human health and the environment.

1.2 FEDERAL REGULATION

In 1976, Congress passed the Resource Conservation and Recovery Act, which mandated the U.S. Environmental Protection Agency (EPA) to regulate the application of solid waste to land. Sludge was defined as a solid waste to be regulated under the Act. "Criteria for Classification of Solid Waste Disposal of Municipal Wastewater Sludge" (hereafter, "Criteria") were published in September 1979 (Federal Register, 1979). Requirements relevant to sludge covered allowable loadings of certain toxicants and criteria to control risk of disease. The major features of the regulation relating to control of disease risk were:

- Unstabilized sludge could not be used on the land.
- Sludge could be used on land if it was treated by processes that reduced pathogens and the sludge's attractiveness to disease vectors (flies, rodents, etc.), and if certain restrictions relating to access, grazing, and type of crop grown were observed.
- If pathogen levels were reduced to below detection levels and vector attraction was reduced, there were no restrictions to sludge use.
- The rules for septage were similar to those for sludge, except that unstabilized septage could be applied to soil if crops for direct human consumption were not grown.

The regulations created a uniform approach for land application. They did not appear to substantially affect the practice of land application. They mostly impacted new construction where plans for sludge treatment would be examined by State and Federal authorities. Although statistics on land utilization have not been kept, the practice appears to have kept pace with the increase in mass of sludge generated in this country. According to a 1984 EPA report (EPA, 1984), up to 40% of the sludge produced by municipal wastewater treatment plants is used on the land or distributed and marketed to the public.

SECTION TWO

COMPONENTS OF DISEASE RISK AND THEIR CONTROL

2.1 PATHOGENS OF CONCERN

2.1.1 Bacteria

2.1.1.1 Types and Measurement

Pathogenic bacteria (i.e., bacteria that create disease) are not normal inhabitants of the human enteric (intestinal) system. They are present when an individual has contracted a bacterial disease or illness. Consequently, they rarely occur in fecal waste, but when they do, high levels are found. Since wastewaters from a sewage treatment plant contain the wastes from many people, pathogens are usually present, but their densities vary depending on the prevalence of bacterial disease in the local community. Frequently, there are long periods when certain pathogenic bacteria are below detection limits in municipal wastewater and in the sludges produced (Farrell et al., in press). Bacterial species present in wastewater and their densities are therefore highly unpredictable.

Kowal (1985) lists several pathogenic enteric bacteria and bacterial species that are of major concern in sludge and a greater number that are of minor concern. The selection was based on the density of the bacteria in sludge, the extent of the disease, and the seriousness of the illness produced. Among bacteria species singled out are Shigella spp., Salmonella spp., and Yersinia spp. All cause enteric disease in large numbers of people in the United States. Most research on bacterial survival in sludge has focussed on Salmonella spp., which include over 1,000 serotypes. These organisms may cause salmonellosis, an acute gastroenteritis. Salmonellae have

been emphasized because they are more frequently identified in sludge than other bacterial species, they cause severe illness with relative frequency, and a reliable quantitation method exists that can detect them.

The densities of pathogenic bacteria in the stool of an infected person may be 10^6/gram (g) (Kowal, 1985). Typical values in sludge are much lower. For example, densities of Salmonella spp. over 10^3/g are encountered infrequently. On the other hand, the normal bacterial inhabitants of the lower intestines are found at much higher densities. Obligate anaerobic bacteria have densities approaching 10^9/g in feces. Facultative bacteria; such as the fecal coliform group, have densities around 10^8/g.

Monitoring sludge on a regular basis to determine the types and densities of pathogenic bacteria present is desirable but, in practical terms, unattainable. Quantitation methods for some bacterial species are difficult and unreliable, and require high skill levels. Too many species would have to be measured, even if measurement were restricted to bacteria of major concern.

The presence of one pathogenic species cannot be used as an indicator of the presence of other pathogenic species because there is no reason for the high incidence of one enteric bacterial disease in a community to correlate with other enteric bacterial diseases. The best indicators of the potential presence of bacterial enteric pathogens in sludge are the facultative enteric organisms that normally inhabit the intestines, such as Escherichia coli, the fecal coliforms, and fecal streptococci. Though these indicators do not correlate well with any individual enteric bacterial pathogen species, they do indicate the presence of human fecal waste, which is the carrier of the pathogens. Thus, they are good long-term indicators of pathogenic bacteria, but will not always correlate well in the short term.

Indicator organisms are frequently used as surrogates for the pathogenic enteric bacteria to reflect their response to environmental exposure or sludge treatment processes. This offers advantages over attempting to measure effects on pathogens directly, because pathogens are generally present in low

densities in sludge and are sometimes absent; consequently, unreasonably long experimental programs are frequently needed to obtain definitive results, especially when the exposure causes large reductions in pathogen densities. The sludge or wastewater can be "spiked" with cultured pathogenic bacteria to increase their densities; however, the responses of cultured organisms are not always the same as those of naturally occurring organisms (Farrah et al., 1986). Indicator organisms, on the other hand, are expected to behave similarly to the pathogenic enteric bacteria because their life processes and ecological niches are similar (they belong to the same class, Enterobacteriaceae). Experimental results indicate that the responses of the indicators and salmonellae to sludge processing do correlate satisfactorily (Farrell et al., in press; Farrah et al., 1986).

2.1.1.2 Effects of Processing

The pathogenic bacteria in wastewater are insoluble solids. The bacteria are small particles with densities only slightly greater than water. Consequently, they settle poorly unless flocculated. They can be removed from the wastewater by filtration. In primary wastewater treatment, bacteria are associated with solids. These solids (and the associated bacteria) settle fairly well, but many escape this step. Collection is greatly improved in the secondary clarifier, where they become enmeshed in the biological solids. These solids autoflocculate and settle, carrying with them most of the bacteria that escaped collection in the primary clarifier.

Wastewater Treatment

Besides merely collecting solids, the wastewater treatment processes may actually reduce numbers of pathogens. Simple sedimentation in a clarifier causes little change (Farrell et al., in press), but biological processes, such as the trickling filter and activated sludge process, may substantially reduce the numbers of pathogens (Farrell et al., in press). These reductions

may be caused by the time of contact, temperature, lytic effect of bacterial enzyme systems, action of bacterial viruses (bacteriophages), and "grazing of protozoa" (Farrah et al., 1986). Farrell et al. (in press) and Lee et al. (in press) report bacterial reductions (based on number of organisms per unit mass of suspended solids) of 1.5 logs in extended aeration systems.

Digestion

The conventional processes of anaerobic and aerobic digestion cause substantial bacterial reductions. Farrell et al. (1985) show reductions of indicator organism densities (colony-forming units [CFU]/100 mL) of about 1 log for salmonellae and 1.7 logs for indicator organisms. Martin (in press) showed that aerobic digestion for 10 days at temperatures averaging 30°C causes reductions of similar magnitude.

Storage

Storage time has an important effect on the density of bacterial pathogens and indicator organisms. Stern and Farrell (1978) have shown that storage at 20°C reduces Salmonella spp. by 2 logs in 3 months and indicator densities by about the same amount. Storage at 5°C was much less effective. Storage of sludge cake would probably show the same effect.

Lime Stabilization

Lime is frequently used to condition or stabilize sludge before disposal. A pH of about 12 essentially eliminates salmonellae and greatly reduces the density of indicator organisms (Counts and Shuckrow, 1975).

Elevated Temperature

The enteric bacteria of concern do not form heat-resistant spores, so they are easily destroyed by elevated temperatures. Stabilization processes that elevate the sludge temperature to 53°C or above for a sufficient time effectively eliminate pathogenic bacteria.

2.1.1.3 Environmental Effects

When sludge is applied to land, environmental conditions reduce bacterial densities. Kowal (1985) reviewed the literature on the survival times of pathogenic bacteria in the environment. Survival times vary widely depending on the initial densities of the pathogens and on environmental factors such as temperature, degree of desiccation, and amount of ultraviolet radiation. Bacterial pathogens in sludge on plant surfaces die off more quickly than those in the sludge on the soil surface, because of more exposure to sunlight and greater desiccation. Kowal indicates that the risk from pathogens deposited on plant surfaces during application should become minimal 1 month after application; however, he recommends that low-growing food crops, such as strawberries, that touch the soil or are splattered by soil aerialized by rainfall not be harvested until 6 months after sludge use.

Bacteria in sludge are effectively filtered by the soil except in cases where the soil is a coarse sand. Gerba et al. (1975) observed that over 91% of the coliforms were trapped in the first centimeter of soil. Soils subject to cracking, such as clay soil in dry weather, pose special problems. Sludge application on such soils after a dry period could be unwise, depending on the proximity of the surface to ground or surface water. Farm soils used to grow row crops (e.g., feed corn, soybeans) are probably superior to forest soils for protecting ground water. Root, insect, and animal holes are destroyed by the soil preparation required for crop production, and soil layers are usually much deeper on farms than in forests. If bacteria should reach ground water, transport within that media is extremely slow and should give ample time for

further reductions in pathogen density. In certain kinds of geology, such as limestone or fractured structures, soil leachate can travel rapidly. Use of sludge on soil where such geology is not protected by a thick soil layer poses an elevated risk.

Bacteria are unique among sludge pathogens in their ability to regrow. Enteric bacteria are facultative and can multiply under aerobic or anaerobic conditions. If they encounter a suitable food source such as bruised or cracked fruit, they can regrow to high densities. They can also regrow to high densities when competition from other bacteria is reduced, even in a low-energy substrate such as well-stabilized compost. Burge et al. (1986) showed that salmonellae innoculated into sterilized compost grew to a higher level for a longer time than salmonellae innoculated into unsterilized compost.

2.1.2 Viruses

2.1.2.1 Types and Measurement

Kowal's extensive review lists the human enteric viruses likely to be present in wastewater and sludge (Kowal, 1985). These viruses are not normal inhabitants of the gastrointestinal tract and their presence indicates an infection that may show no symptoms. Viruses are released from cells in the gastrointestinal tract in which they are replicating into the intestines and, consequently, are present in fecal discharges. They are generally adsorbed to or enmeshed in solids.

Kowal lists five subclasses of enteroviruses (e.g., polio-, Coxsackie-, Echo-) as well as hepatitis A virus and rotaviruses. These viruses cause a wide variety of illnesses; for example, hepatitis A virus causes approximately 40,000 to 50,000 cases of infectious hepatitis in the United States. Rotavirus causes acute gastroenteritis, primarily in children. The enteroviruses cause many diseases including paralysis, diarrhea, meningitis, heart disease, and respiratory illness. Most infections are asymptomatic, so

many more infected people shed viruses than indicated by disease incidence numbers. A particular virus may or may not be present in the wastewater, depending on the presence or absence of infected people in the community.

There are a variety of methods for identifying viruses in sludge. The most common procedure, the plaque assay method, is described by Bitton (1970). A viral suspension extracted from sludge is placed on the surface of an animal cell monolayer that has been grown on the interior wall of a glass bottle. After providing time for adsorption of the viruses to the cell layer, an overlay of agar is poured over the monolayer to immobilize the system and provide nutrient and moisture for the cells. Time is allowed for the viruses to invade the cells and replicate. Each virus invasion leads to a zone of infection where cells have been destroyed. This localized area is called a plaque. Staining or other techniques are used to identify plaques. Unfortunately this and other virus identification methods are expensive and require skilled personnel.

The plaque-forming method currently in use identifies a wide variety of enteroviruses (Bitton, 1980). The number depends on the types of cells used in the test. Some important viruses -- Hepatitis A and rotavirus -- are not enumerated by this method. Serological methods can be used to determine the specific viruses that formed the plaques but this adds another level of complexity to an already complex procedure.

The densities of viruses found in sludge range widely. Brashear and Ward (1982) report 5-145 PFU/mL (plaque-forming units per milliliter) of a raw sludge. Assuming 2% solids in the sludge, this is equivalent to 250-7,000/g of solids. Other sludges could show higher or lower densities.

Less information is available on virus densities than on indicator bacteria or Salmonella spp. densities because of the complexity of the method for determining densities and the special skills and equipment needed. Although the plaque-forming method does not indicate the presence of some viruses, it can enumerate enteric viruses of several types. It could serve as

a useful indicator test for all enteric viruses, except for its aforementioned cost and complexity.

An alternative to the enteric virus test to indicate viral densities is to use the fecal coliforms and/or fecal streptococci test for this purpose. As with pathogenic bacteria (see above), the fecal indicators are not expected to correlate over the short term with virus densities; however, since they indicate the presence of fecal wastes, they will correlate well over the long term. Indicator organism densities can be used to indicate the effect of sludge processing conditions on viral densities if available data indicate a satisfactory correlation between the effect of the condition on viral densities and indicator organisms.

Such correlations appear to be adequate for some processing procedures but not for others. For example, Berg and Berman (1980) demonstrated that, in anaerobic digestion, the decline in viruses showed a reasonable relationship to the decline in fecal coliforms and fecal streptococci. On the other hand, irradiation of sludge by gamma rays or high-energy electrons requires 20-30 kilorads to reduce coliforms by 1 log (Ward, 1981), and ten times that dose to achieve the same reduction in viruses. With irradiation, a relationship exists between the declines in the two types of organisms, but it is inappropriate. The coliforms could not be an indicator for viruses because they could be reduced to negligible values while viruses were still present.

2.1.2.2 Effects of Processing

Wastewater Treatment

Viruses are subcolloidal in size and would not be expected to settle out or to be filtered out in wastewater treatment; however, they have a strong tendency to adsorb to solids. Consequently, most of them are removed with the solids and are found in the sludge streams. The sedimentation processes in clarifiers do little to reduce viral numbers. However, biological processes,

such as the activated sludge process, do reduce viruses. Time of exposure is a factor. Virus densities decline with time even in nonaggressive environments such as river water (Clarke et al., 1964). Because sludges are retained in wastewater treatment processes for periods ranging from a few days to 30 days, declines based on time and temperature of exposure occur. Bacterial enzyme systems may reduce the numbers of some viruses.

Digestion

Conventional anaerobic and aerobic digestion of sludge reduces viral densities depending on the temperature, time, type of processing, and operation of the system. Farrell et al. (1988) have shown that the manner of feeding and withdrawing the sludge (fill/draw versus draw/fill) has a small effect on virus survival. Draw/fill feeding yields better viral reductions. Berg and Berman (1980) and Farrell et al. (1985) show the reductions achieved by digestion at a large wastewater treatment plant. Farrah et al. (1986) and Martin (in press) show effects of aerobic digestion on viral survival.

Lime Treatment

Strauch (1982) presented data demonstrating that lime treatment to pH 12 produces rapid and large reductions in viral populations. Chlorine treatment is expected to cause similar reductions. Acid treatment is less effective in reducing virus densities. Exposure to pH 3.5 is typically a step in the procedure for enumerating viruses.

Elevated Temperature

Stabilization processes that elevate the sludge temperature to greater than 53°C reduce or even totally eliminate enteric viruses. These processes

include thermophilic anaerobic and aerobic digestion, composting, and pasteurization.

Storage

Storage for a period of time is effective in reducing viral densities. The reduction is a function of temperature. Stern and Farrell (1978) found that less than 3% of viruses survived in digested sludge stored for 4 months at 20°C, whereas 33% survived at 5°C.

2.1.2.3 Environmental Effects

Adverse environmental effects reduce viral densities when sludge is applied to land. The rapidity of reduction depends in part on the proximity of the sludge to the land surface. Sorber and Moore (1986) compare data from several investigators and show that the longest times for 1-log and 2-log reductions in densities were 30 and 52 days when sludge was applied to or within 5 centimeters (cm) of the soil surface. The average time for die-off was generally much shorter than these figures. For deeper application (15 cm), they cite the work of Damgaard-Larsen et al. (1977) which showed 56 and 100 days required for 1- and 2-log reductions.

Viruses in sludge adhering to the surface of crops die off even more rapidly because exposure is more severe. Larkin et al. (1976) showed an over 2-log (base 10) reduction in poliovirus densities on lettuce and radishes about 14 days after spray-irrigation with sludge.

2.1.3 Protozoa

2.1.3.1 Types and Quantification

Numerous protozoa invade the human gastrointestinal system and cause disease. Their cysts are found in wastewater and sludge. The three most important noted by Kowal (1985) are Entamoeba histolytica, Giardia lamblia, and Balantidium coli. These organisms are known to transmit human disease through a water route and by direct contact. The characteristic illness is diarrhea.

Protozoan cysts are excreted in great numbers from infected persons. Infection rates in the population are low except for Giardia lamblia, where the carrier rate may range from 1.5-20% (Benenson, 1975). Levels in wastewater have been estimated to be 4 cysts/L for Entamoeba histolytica (Foster and Englebrecht, 1973) and 10^4 to 2 x 10^5 cysts/L for Giardia lamblia (Jakubowski and Ericksen, 1979). The densities of protozoa in sludge are not known. If, as expected, most are trapped in the sludge, densities on a volume basis would be about 200 times these figures.

2.1.3.2 Effects of Processing

Little is known about the survival of protozoan cysts when sludge is processed. Based on the lack of information in the literature, Pedersen (1981) suggests it is unlikely that many survive anaerobic digestion. Recent information from Seattle (Metro, 1983) indicates that G. lamblia is present in raw sludge but absent from digested sludge. Yanko (1988) was unable to recover protozoan cysts from composted sludges, heat-dried sludges, and some air-dried sludges. However, processing conditions for these sludge products were severe.

The acknowledged transmission of protozoan cysts by water should not lead to the conclusion that transmission by sludge is likely. Transport of cysts in wastewater to a susceptible host is possible in a matter of hours after discharge, whereas transport of cysts in sludge to a susceptible host may take many days.

2.1.3.3 Environmental Effects

Kowal's review (Kowal, 1985) cites work by Rudolfs et al. (1951) that shows very short survival of Entamoeba histolytica on soil: 18-24 hours on dry soil and 42-72 hours on moist soil. In dry soil, Beaver et al. (1949) showed survival of 10 days.

Survival on plants should be shorter than on soil. However, Tay (1980) reported isolation of both G. lamblia and E. histolytica on fruits and vegetables from farms irrigated with wastewater. No information was found in the literature on the survival of G. lamblia.

2.1.4 Helminths

2.1.4.1 Types and Quantification

The helminths of concern are the nematodes, or roundworms, and the cestodes, or tapeworms. The most common helminths pathogenic to man and likely to be found in sludge are:

- Ascaris lumbricoides (human roundworm)
- Ascaris suum (pig roundworm)
- Trichuris trichiura (human whipworm)
- Taenia saginata (beef tapeworm)

Taenia solum (pork tapeworm)

Toxacara canis (dog roundworm)

Details of the intricate life cycles of these helminths and the diseases they cause are discussed by Kowal (1985) and Faust et al. (1975). Ascaris create pneumonitis when the ingested larvae migrate through the lungs. The human roundworm develops in the small intestine with potential blockage if a number of worms are present. Toxacara canis larvae migrate blindly in the human body, where they can do serious damage to viscera and other organs, including the eyes. The tapeworms can cause pain and digestive disturbances. Tapeworm eggs primarily are a hazard to livestock. When eggs are ingested, larvae are produced that eventually form cystercerci that cause damage to the animal's organs. Humans ingest the cysts from poorly cooked meat, develop the tapeworm, and release the eggs in the feces. Animals ingest eggs when they graze, which completes the cycle.

Reimers et al. (1981) report that Ascaris spp. have the highest concentration of any helminth in sludge. Ascaris spp. are the hardiest of all helminths to sludge processing and environmental exposure.

2.1.4.2 Effects of Processing

Because of their high density and relatively large size (0.07 millimeters (mm)), helminth eggs in wastewater are concentrated into the sludge by wastewater treatment. Conventional sludge stabilization processes, such as aerobic or mesophilic anaerobic digestion, have little effect on the number of viable eggs. Even exposure to harsh conditions, such as treatment with lime to pH 12, has little effect. The use of strong acid embryonates the larvae but does not significantly reduce their viability. Thermal treatment above 53°C, such as is attained in thermophilic aerobic or anaerobic digestion, composting, or pasteurization, is effective in destroying helminth eggs. Combinations of processing steps, such as alkali treatment to high pH combined with desiccation for an adequate time period, are effective in destroying

helminths (Burnham, 1988). Long-term storage (2 years) in simulated lagoons at 25°C has been shown to destroy the helminth eggs found in sewage sludge (Kaneshiro and Stern, 1986). Reimers et al. (in press) have confirmed this finding in a full-scale demonstration in Louisiana and Texas.

2.1.4.3 Environmental Effects

Kowal's review (Kowal, 1985) observes that the eggs of the hardier helminths survive for long periods in the soil. Jakubowski (unpublished) reported quantitative information showing that helminth eggs in surface-applied sludge died off within a year after application, whereas helminth eggs in sludge mixed with soil showed only a 50% reduction after 5 years. Periodic cultivation of the soil increased the die-off for a porous soil but not for a heavier soil.

Helminth survival on the soil surface or on crops is reduced by desiccation and other adverse conditions such as freeze-thaw cycles and sunlight. Densities appear to be reduced to negligible levels in less than a year.

2.2 TRANSPORT OF ORGANISMS

The pathogens in sludge applied to land pose a disease risk only if there are routes by which they can contaminate man. The principal means of contamination are ingestion and inhalation. Absorption through the skin is believed to be a minor risk. Sludge may be transported to man by many routes: aerial, ground water, or surface water; adherence to objects that are inhaled or ingested; surficial or internal contamination of crops eaten by humans; and vectors. The vectors may be flies, mosquitoes, fleas, or rodents, as well as other animals that transport disease organisms to humans either mechanically or by biological processes.

2.2.1 Air Transport

Exposure to aerially transported sludge can occur if dust or spray is inhaled. Sludge is frequently applied to land as a liquid using a splash plate on the back of a truck; sometimes the sludge applicator is a high-pressure nozzle with a range of over 100 meters (m). Heat- or air-dried sludge may be dry enough to create a dust when handled and applied. Movement of equipment may also create dust if the soil dries out after sludge application. The dust or aerosol may be inhaled and usually ends up in the gastrointestinal system.

Kowal (1985) notes that "aerosol shock" substantially reduces bacteria and virus numbers when sprayed wastewater forms an aerosol; however, this information may not be directly translatable to sludge spraying. Sludge typically contains 2-5% suspended solids and, when sprayed, forms relatively large particles. These particles settle to the ground faster than the drops of a wastewater spray and are less likely to evaporate down to a fine aerosol that can be transported long distances. Harding et al. (1981) found fecal indicator organisms in air samples taken when sludge was applied by high-pressure sprays, but at much lower levels than at wastewater application sites. Tank truck application using low-intensity sprays produced little elevation of fecal indicator densities. Sorber (1984) concluded that spraying sludge with high-energy sprays would not represent a health threat to individuals more than 100 m downwind. A buffer zone between a site using high-energy spraying to apply sludge and any area open to the public seems appropriate.

No precautions to reduce aerial transport appear to be necessary when liquid sludge or sludge cake is applied using low-energy means. By the time, this sludge has dried sufficiently to create dust, the pathogens have probably been greatly reduced. In dusty environments, workers generally work in enclosed cabs on equipment or wear dust masks. Travel of dust is generally

limited (e.g., the dust from plowing or disking on a farm field is primarily local).

For sludge products that create dust as they are applied (as might occur with a heat-dried sludge), the only precautions that can be taken to protect the person applying the sludge are using a respirator or reducing the sludge pathogens to insignificant levels.

Aerosols created by low-energy spraying create negligible effects. High-energy spraying poses a hazard primarily to workers; however, this hazard can be minimized or eliminated by equipping workers them with protective devices. Other work practices, such as spraying only in the day time and ensuring that distance from near neighbors exceeds 100 m, will also help reduce any potential health hazard from sludge spraying to insignificant levels.

2.2.2 Groundwater Transport

When sludge is applied to the land surface, the soil and the sludge particles form an effective filter mat. For the most part, only soluble and colloidal particles enter the soil. The larger organisms, such as helminth eggs, are retained on the land surface; however, virus particles and, sometimes, bacteria are small enough to potentially pass through the soil to ground water. The mechanisms of removal of these organisms during soil transport are quite different: bacteria are primarily removed by filtration processes whereas viruses are removed by adsorption.

The literature cited by Kowal (1985) shows that coarse sand is the soil medium most conducive to pathogen transport; it does not provide a good filter medium to remove bacteria and is a poor adsorbent for viruses. Fine-grained soils, on the other hand, provide good removals for both. Cracks in soils caused by desiccation and root, insect, and animal holes can allow substantial transport of organisms to the subsoil. Similarly, fissured rock and limestone beneath the soil can allow transport. However, because liquid is only

occasionally present in soil -- as a result of sludge application or rainfall -- the risk of potential transport of sludge or sludge pathogens to ground water is minimized. By contrast, a septic tank leach field creates a far greater risk of groundwater contamination because the leach field contains flowing pathogen-laden water that directly encounters all the subsurface pathways that may exist in the soil. Similarly, a wastewater application site that receives the wastewater equivalent of 200 cm of rainfall per year provides a far greater driving force for virus movement than sludge addition, which ordinarily contributes only about 2 cm additional water loading to the annual rainfall loading at a site.

Viruses in particular appear to have a potential to migrate to ground water; however, their movement to and within ground water is slow because the water itself moves slowly, and because the viruses adsorb and desorb on the soil, further slowing their progress (Landry et al., 1980). A typical maximum survival time for viruses is 170 days (see Table 12 in Kowal's 1985 review). If, as is likely, movement to ground water is slow, and the movement of ground water itself beyond the site boundary is also slow, the potential for virus contamination of ground water beyond the site will be negligible. At sites where sludge loadings are high, soil layers are thin, and/or subsurface conditions are unknown (such as in forests), buffer strips should be provided to avoid movement of viruses to ground water with subsequent potential transmission off site.

2.2.3 Surface Water Transport

Surface water can potentially be contaminated by runoff from a land application site, or by rainwater moving pathogens transversely below the ground surface through root holes, animal burrows, and fissures in rock strata. Movement through fissures is likely only for sludge applied to forest soil. Helminth eggs are transported by rainwater but, because of their high density, they tend to drop out of moving streams and concentrate in deposits in a manner roughly analogous to deposits of gold in stream beds. On the

other hand, bacteria and viruses can be carried by fine solids wherever the runoff goes. As noted earlier, bacteria and viruses generally die off about 1 month after application to the soil surface, so the potential health hazard from runoff disappears after this time. Runoff can be controlled by using buffer strips of vegetation to remove solids from runoff. Runoff can be controlled more directly by collecting and holding it in ponds for a sufficient time to reduce microbiological densities.

2.2.4 Adherence to Objects

Sludge will adhere to crops, soil, and equipment. Viruses and bacteria on exposed surfaces die off in less than a month; some helminths probably die off less rapidly. Risk can be controlled by restricting the movement of objects from the site until at least 1 month following application. Equipment or animals that must move on and off the site shortly after sludge application should be washed to eliminate risk.

2.2.5 Transport by Vectors

Transport of sludge by vectors is difficult to quantify. Several varieties of flies are attracted to and breed in sludge. Primary sludge contains food wastes attractive to rodents and some birds.

Vectors carry disease in several ways: by complex means (such as in some mosquito-borne illnesses), by becoming infected themselves (as with salmonellosis), or by mechanical transport. The only effective way to eliminate vector transport is to make the sludge unattractive to vectors (i.e., by treating the sludge prior to land application).

2.3 VECTOR ATTRACTION

Sludge from wastewater treatment processes is generally noxious and therefore attractive to vectors. Sludge produced in primary treatment (simple settling) is especially noxious. It contains identifiable fecal material and food scraps and is usually devoid of oxygen. Primary sludge putrefies rapidly and releases odorous compounds, a process that eventually results in vector attraction. Sludge from secondary treatment, such as waste-activated sludge, contains suspended solids that escaped primary clarification, as well as biological solids. Though not as unpleasant as primary sludge, secondary sludge also attracts vectors. Some sludges may be processed for such a long time that they do not attract vectors. For example, an extended aeration sludge may be so thoroughly stabilized by long-term aeration that it does not putrefy and is unlikely to attract vectors.

The attractiveness of a sludge to vectors can be reduced in various ways, some permanent and some temporary. For example, reduction of sludge food value and odor by long digestion permanently reduces the sludge's attractiveness to vectors. Drying temporarily reduces vector attractiveness, but the sludge will attract vectors again if it is rewetted. Both permanent and temporary methods are valid approaches to reducing vector attraction, although for methods that offer only a stasis in vector attraction, the period of stasis must last until the sludge has been utilized.

Scientific tests to measure the attractiveness of a sludge to vectors have not been developed, although there appears to be no great technical difficulty in developing appropriate tests. Essentially, there are three requirements: a standardized population of vectors, a standard way of presenting the sludge to the vectors, and a measure of the interest of the vectors in the sludge (e.g., number of visits to the sludge by a "standard" group of flies). Different tests would be needed for different vectors. If such tests were developed, their results could be correlated to more easily measured properties of the sludge, such as specific oxygen uptake rates after aerobic digestion or reduction in percent volatile solids by anaerobic digestion.

Interest of vectors would be expected to be inversely related to the specific oxygen uptake rate or the percent reduction in volatile solids.

Any vector attractant test result would not be an absolute property of a sludge but would be influenced by the sludge's temperature and solids content, the test duration, ambient temperature and humidity, and even wind speed. For example, vectors might not be attracted to a sludge at 15°C but might be drawn to the same sludge at 25°C. Consequently, a satisfactory test result or a satisfactory value of some correlated parameter such as percent volatile solids reduction does not ensure that the sludge would not attract vectors under adverse conditions.

"Criteria" (Federal Register, 1979) lists several processes that have been determined to reduce vector attraction. Since tests to measure vector attraction did not exist when the Criteria were developed, field experience was used for some processes to determine whether the resulting sludge would attract vectors. In this "cut and try" approach, sludges with a range of values of a parameter thought to be associated with vector attraction were placed in the field, and the degree of vector attraction was observed. This route was formally followed for lime stabilization (Farrell et al., 1974; Noland et al., 1978; Counts and Shuckrow, 1975), one of the processes listed in "Criteria" (Federal Register, 1979). Prior field experience with other processes, such as anaerobic and aerobic digestion, permitted specifying the conditions for these processes that reduced vector attraction.

The processes listed in "Criteria" that reduce vector attraction are listed below along with a brief note on the action that reduces vector attraction.

- Aerobic digestion (mesophilic or thermophilic). Reduction in food value.
- Anaerobic digestion (mesophilic or thermophilic). Reduction in food value.
- Lime stabilization. Temporary stasis in bacterial activity caused by high pH. The effect disappears when pH falls.

- Air drying on sand beds. Reduction in food value and reduced moisture. The sludge would have to be biologically stabilized before it would be possible to expose it to the environment on sand beds. Additional biological oxidation occurs as the sludge slowly dries on the sand beds.

- Heat drying. Temporary stasis that disappears when sludge moisture content increases.

- Composting (mesophilic or thermophilic). Reduction in food value.

- Heat treatment. Temporary. Vector attraction is unlikely only if the sludge is kept sterile. The proposed regulation imposes certain restrictions on this form of treatment in order to reduce vector attraction.

The processes in "Criteria" that reduce vectors also have to reduce pathogens to either of two levels. The proposed regulation disentangles vector attraction from pathogen reduction. Greater freedom is available to develop new processes or combinations of processes to reduce pathogens, because it has been possible to establish a common performance target for pathogen reduction. No common target for vector attraction appears possible, primarily because there is no standardized test to measure vector attraction. The subjective target that "vector attraction be reduced" is unusable for regulatory purposes. Consequently, the regulation proposes four alternative performance standards and one method of application for demonstrating reduction of vector attraction.

If a field test to quantify vector attraction is developed, future regulations could conceivably establish a common performance target for reduction of vector attraction. This would allow plant operators the freedom to select any types or combinations of processes to reduce vector attraction as long as the end point is met. As discussed above, the likelihood that such a test can be developed is small.

2.4 INFECTIVE DOSE

To establish a level of concern about the disease risk posed by a particular sludge pathogen, the infective dose for that organism must be known. Infective dose is the minimum dose of a pathogen needed to cause infection.

Kowal (1985) critically reviewed the literature on infective dose for all pathogen groups of concern. He concludes that although infective doses for most species of bacteria are high (i.e., many thousands of organisms are required to cause infection), they can be low in some circumstances. He cites Blaser and Newman (1982), who indicate that the infective dose for Salmonella spp. may be less than 1,000 organisms. For Shigella, the infective dose is low -- 10 to 100 organisms (Keusch, 1970). Ward and Akin (1984) are even more pessimistic, citing work by D'Aoust (1985) indicating that Salmonella spp. may be infective at doses below 10 organisms.

Currently, the infective dose for viruses is thought to be low (Kowal, 1985) -- on the order of 10 virus particles or less. For protozoa, the infective dose is likewise low. Kowal (1985) observes that single cysts of Entamoeba coli have produced infections. For helminths, single eggs are infective to man. The extent of the infection is dose-related, since most of the worms produced do not multiply in man. However, an infection may sensitize individuals so that subsequent light infections cause allergic reactions.

For all pathogens of concern, the infectious dose is small. It is therefore prudent to minimize exposure. If the conditions of land application make sludge ingestion probable (e.g., sludge is applied to food crops to be harvested shortly after application), the sludge should be essentially devoid of pathogens.

SECTION THREE

THE PROPOSED REGULATION

3.1 BACKGROUND

Nine years have elapsed since the publication of the "Criteria" in 1979. Experience in this period has demonstrated that the pathogen requirements have posed no great burden for most large treatment plants, but some large and many smaller treatment plants have encountered compliance problems. These plants generally produced an adequately treated product and utilized it in a safe manner, but they had difficulty consistently meeting the technology-based requirements of the regulation. This experience suggested that the regulation should be reviewed and adjustments made to address inequities, while continuing to provide adequate protection from disease risk.

The major difficulties with the current regulation and the proposed solutions are briefly described below:

(1) Shifting from Technology-based to Performance-based Standards. As noted earlier, "Criteria" defines two classes of treatment: PSRP (Processes to Significantly Reduce Pathogens) and PFRP (Processes to Further Reduce Pathogens). These processes reduce pathogens and vector attraction. Some pathogens survive PSRP treatment and remain in the sludge; for this reason, the existing regulation imposes constraints on crops grown and access at sites treated with sludge produced by a PSRP. With PFRPs, pathogens are reduced to such a low level that constraints are not needed. The PSRP and PFRP processes were "technology-based." The process descriptions (time, temperature, and other process conditions) were given but performance was not specified. This created an inflexible condition. New technology was difficult to introduce because there was no identified goal. The proposed regulations replace all technology-based standards with performance-based standards. This allows much freer exercise of creativity because the goals for new processes or process combinations are clearly identified.

(2) Separating the Requirements for Pathogen Reduction and Reduction of Vector Attraction. "Criteria" identifies a limited number of single-step processes that accomplish the goals of pathogen reduction and reduction in vector attraction. There is no benefit in connecting these goals or requiring them to be accomplished in a single step. The proposed regulation separates these requirements and allows for combinations of more than one process to accomplish either or both goals.

(3) Incorporating the Contribution of Wastewater Treatment to Pathogen Reduction. "Criteria" implicitly assumes that sludges from all wastewater treatment units have about the same pathogen density; however, continuing research (see below) has revealed that the pathogen burden in raw sludges varies depending on the nature of the wastewater treatment process that produces the sludge. It now appears to be much more likely that the pathogen densities (number/gram volatile suspended solids sludge [no./g VSS]) in the incoming wastewater to different treatment plants will be similar, than that the sludges produced by wastewater treatment will have similar pathogen densities (no./g VSS). In the proposed regulation, emphasis has therefore shifted to require that the reduction in pathogens from untreated wastewater to treated sludge be made equivalent rather than requiring that all raw sludges get equivalent treatment after collection.

(4) New Requirements for Well-Stabilized Sludges. Operators of extended aeration plants have frequently experienced difficulty in meeting PSRP requirements for their sludges because their untreated sludges were well stabilized and could not meet requirements for further stabilization. A new classification has been created that allows these well-stabilized sludges to be applied to land provided they meet tighter crop and access restrictions.

By making the changes outlined above, the proposed regulation effectively addresses the difficulties that have been encountered with the existing "Disease" section of 40 CFR 257 without compromising protection of human health and the environment.

3.2 SCIENTIFIC BASIS OF THE PROPOSED REGULATION

This section discusses the component parts of the proposed regulation following the exact format of the regulation. It presents the underlying logic supporting the approach as well as the scientific support for selecting specific requirements. Each topic discussed is keyed into the numbering system used in the regulation.

3.2.1 Specialized Definitions (§503.51)

Some of the definitions in the regulation need no explanation. Those discussed below are unique or different from common usage and require elaboration.

3.2.1.1 Average Density of Microbial Organisms

This term is defined as the number of organisms per unit volume of sludge divided by mass of volatile suspended solids per unit volume of sludge. It is the number of organisms per unit mass of volatile suspended solids in the sludge. Number is a count which, for bacteria, may be predicted by an MPN (most probable number) or a count of colony-forming units (CFU); for viruses, it may be a plaque count; for helminth eggs or protozoan cysts, it may be an actual one-for-one enumeration. The density is determined by measuring (1) the number of pathogens in a given volume of sludge, and (2) the suspended volatile solids in the same volume, and then dividing these two results to obtain the number per unit mass. In the following discussion, density is identified by its actual density units (e.g., CFU/g VSS) or as "density (mass basis)."

The density as defined above (no./g VSS) is different from the organism density used in drinking water technology, where density is appropriately defined as the number of organisms per unit volume. This volume-based definition would be of little value in sludge processing, where the interest

is in numbers related to sludge solids. For example, in dewatering, where little organism destruction occurs, density per unit volume increases dramatically when the water is removed from the sludge. Comparing organism densities on a volume basis before and after dewatering tells little about the fate of microorganisms. Tracking the density per unit mass of volatile solids gives us the information we desire, that is, that densities on the mass basis show little change, indicating the minimal effect of the process on microorganisms.

3.2.1.2 Pathogen Reduction

In the proposed regulation, pathogen reduction means the reduction in densities of pathogens on a mass basis (number per unit mass of volatile suspended solids). A quantitative measure of pathogen reduction is a concern primarily for bacteria and viruses. The densities (mass basis) in the sludge leaving the plant are compared to the densities (mass basis) in the incoming wastewater. For a batch or a plug-flow process, reductions could be determined from a measurement at the start (or inlet) and at the end (or outlet) of the operation. In wastewater and sludge processing, flow is usually continuous or periodic, flowing streams are usually mixed or recirculated, and sludge residence times can exceed 20 days. Consequently, on a given day, inlet and outlet concentrations may bear no relationship to one another. Reductions in bacterial and viral densities (mass basis) are best estimated by comparing the average of the logarithmic densities determined on samples collected before and after treatment over several weeks of steady operation.

3.2.1.3 Specific Oxygen Uptake Rate (SOUR)

This parameter is determined in a standard test that measures the rate at which a sludge consumes oxygen per unit mass of solids present. A high SOUR indicates a large and active bacterial mass and is likely to putrefy rapidly. A low SOUR indicates that bacteria present are not metabolically active. This

generally indicates that the bacteria have consumed the available food resources and that the sludge will not putrefy rapidly. The test is only appropriate for sludges that have a high proportion of aerobic bacteria. It is not appropriate for untreated, limed, or anaerobically digested sludges.

3.2.1.4 Volatile Suspended Solids

The volatile solids concentration and the changes that occur in it are parameters of concern for some of the processes that reduce vector attraction, such as digestion. Volatile solids include volatile matter in both suspended and dissolved solids. Volatile suspended solids concentration is the parameter of concern when quantifying microbial densities, because the microbes are primarily associated with or are particulate solids. Analytically, it is easier to determine volatile solids concentration than volatile suspended solids concentration. When the dissolved volatile solids concentration is less than 5% of the total volatile solids concentration, volatile solids concentration can be used in place of volatile suspended solids concentration without introducing serious error.

3.2.2 Class A Requirements

The regulation proposed performance-based standards for three classes of pathogen reduction: Class A, Class B, and Class C. Classes B and C also include sludge use and site access restrictions. The specific requirements for these classes of pathogen reduction and the scientific basis for them are discussed in the rest of this section.

3.2.2.1 Pathogen Reduction Requirements (§503.52)

Class A pathogen reduction requires that densities of pathogenic bacteria, animal viruses, protozoa, and helminth ova be reduced to nondetectable levels. This requirement is necessary because there are no restrictions on the use of

sludge that has received Class A treatment. People can come into direct bodily contact with sludge at any time after application, possibly inhaling dust or ingesting small amounts of sludge. Consequently, the presence of concentrations of pathogens that could cause disease must be avoided. As observed earlier, ingestion of only one viable animal virus, protozoa, or helminth egg can cause an infection (Kowal, 1985). For bacteria, the infective doses are normally much higher, but may be less than 10 organisms during outbreaks (D'Aoust, 1985). In view of these low minimum infective doses, it appears appropriate to require all pathogens to be below detectable limits in Class A sludges.

Use of Fecal Indicators for Thermal Processes

The regulation allows the use of reduction of fecal indicators to indicate elimination of pathogens, if the mechanism that destroys the pathogens is primarily thermal. If temperatures of 53°C or above are used to destroy the pathogens, reduction of fecal coliforms and fecal streptococci to densities below 100/g VSS will ensure that pathogens are eliminated. Exposure to 70°C for one-half hour will produce reductions of this magnitude; exposure to 55°C for three days or 53°C for five days is expected to produce similar results.

Both laboratory and field experience suggest that reduction of fecal indicators to low levels satisfactorily indicates the reduction of pathogens to insignificant levels by thermal processes. The fecal indicators are reduced at rates generally comparable to many of the pathogens, particularly to bacterial pathogens, but their initial concentrations are ordinarily many orders of magnitude (i.e., factors of ten) higher than the pathogens. Even if they should decline faster than some pathogens (and they do decline faster than some viruses), appreciable numbers would still survive to serve as indicators when the pathogens have long since diminished to negligible values.

Berg and Berman (1980) showed that when sludge was thermophilically digested at 49°C in a full-scale digester, viruses were eliminated or reduced to low values while substantial numbers of fecal coliforms and fecal

streptococci survived. The ratios of fecal coliforms to viruses and fecal streptococci to viruses in the final product averaged 12,000:1. Median viral density (volume basis) in the raw sludge fed to the digester was 1,500 PFU/100 ml, which is a typical viral density in untreated sludge. The indicator organisms would clearly serve as a good indicator: An indicator density of 100/g VSS would indicate a viral density of 0.01/g VSS, a factor of 30 below the detectable limit. For the same thermophilic digester, Farrell et al. (1985) reported results from 27 measurements of bacterial densities. Salmonellae, which averaged in the normal range -- about 210/g VSS -- in the undigested sludge, were reduced to below detectable levels in all cases. Fecal coliform density (mass basis) was reduced 5 logs but final densities averaged 390 CFU/g. Fecal streptococci densities (mass basis) were reduced 2.7 logs and fecal densities averaged 7,600 CFU/g.

For composting -- another process that destroys pathogens using thermal means -- Iacaboni et al. (1984) reported reductions in fecal and total coliform densities and salmonellae densities during full-scale windrow composting in Los Angeles. Their work was divided in three phases. In Phase I, data were obtained with low windrows and relatively dry sludge cake. Phase II data were obtained with wetter sludge cake, and temperatures above 55°C were frequently hard to sustain. Salmonellae and coliform densities were elevated and provided a good test of the utility of using coliforms to indicate the presence of salmonellae. In a third phase, these investigators used high windrows. During these tests, fecal indicators were generally less than 100/g solids and salmonellae were rarely detected.

The coliform and salmonellae data are shown in Table 3-1. These results show that total and fecal coliforms survive the thermal stress of composting (temp. range 45-65°C) better than salmonellae. When their densities were low (less than 100/g), salmonellae were absent. When coliform densities were above 100/g solids, the likelihood that salmonellae were present was high. Salmonella spp. densities in the incoming sludge were approximately 1.7×10^5 MPN/g for Phase I and 5.8×10^4 MPN/g for Phase II studies. (In such comparisons, it is important to know that ample salmonellae were entering. If salmonellae are not present in the incoming sludge, their absence in the final product is no evidence that the process kills salmonellae.)

In recent work reported by Yanko (1988), complete microbiological analyses was carried out on composts and other sludge products. The composts were prepared at thermophilic conditions (40-70°C). Results showed substantial survival of indicators but complete absence of viruses. In an appendix to the cited report by Iacaboni et al. (1984), Yanko does not recommend fecal indicators as indicators of virus density, but his reason appears to be that the fecal indicators may regrow. Thus, a high indicator density might not indicate a correspondingly high viral density. In this case the indicators might be excessively conservative indicators of the presence of viruses. Nevertheless, the conclusion that low fecal indicators indicate the absence of viruses is still valid.

Yanko's work included enumeration of Ascaris eggs in sludge products intended for distribution and marketing. These products were either composted at temperatures exceeding 53°C or were air-dried in hot climates. In 350 examinations, Ascaris were recovered but none were viable. It is therefore reasonable to conclude that if the process destroying microorganisms utilizes thermal means at temperatures above 53°C, Ascaris will also be destroyed. Fecal indicators less than 100/g and temperatures above 53°C are good evidence of their destruction. Yanko also observed that it was extremely unlikely that protozoan cysts could survive conditions that would destroy viruses and Ascaris spp.

The origin of the 53°C requirement requires discussion. This critical temperature is derived from results obtained by Brannen et al. (1975). These authors showed that Ascaris egg densities were reduced 2 logs (base 10) in about 5 minutes at 55°C, in 60 minutes at 51°C, and showed no reduction at all after 2 hours at 47°C. Thus, to ensure Ascaris destruction, the required minimum sludge processing temperature must exceed this threshold for Ascaris sensitivity. Based on Brannen et al.'s data, a temperature of 53°C was selected as sufficient to cause a rapid reduction in Ascaris density.

Nonthermal Processes

For processes that use nonthermal means to destroy pathogens, fecal indicators are not adequate for indicating pathogen reduction. Generally, pathogen reduction can be adequately gauged by focusing on the one pathogen type least susceptible to the adverse conditions of the process. For example, Ward (1981) points out that the radiation dose to inactivate 90% of viable viruses in sludge is about 10 times the dose required to inactivate enteric bacteria. Larger organisms, such as helminth ova, are even more susceptible to radiation than bacteria. Consequently, for processes that use radiation to destroy pathogens, adequate pathogen destruction can be ensured at doses sufficient to reduce typical maximum viral densities to below detection limits.

For processes that treat sludge by chemicals, helminth ova are likely to be the most resistant organism type, since the shells of the ova are resistant to penetration by chemicals.

Unique and Novel Processes

For unique and novel processes, data on all the various pathogen types are necessary to demonstrate adequate destruction. If one organism type proves hardier than the others it can then be used as an indicator. If test data demonstrate that this organism was present initially at typical concentrations and was reduced by treatment to below detection limits, then it can be safely assumed that the other pathogens are likewise absent.

Protecting Against Regrowth

The regulation specifies that, to meet Class A requirements, vector attraction must be reduced simultaneously with or after the pathogen reduction. This requirement is necessary for the following reason. To meet Class A requirements, pathogens must be reduced to below detectable levels.

In achieving these reductions, the nonpathogenic bacteria in sludge are also destroyed. These bacteria normally act as competitors with pathogenic bacteria and help prevent regrowth. When they are absent, as in Class A sludges, explosive regrowth can occur. Processes that reduce vector attraction add nonpathogenic bacteria back into the sludge, so when vector attraction occurs simultaneously with or shortly after pathogen reduction, explosive regrowth is prevented.

Several sludge treatment processes simultaneously reduce pathogens and vector attraction. This is not the case, however, with heat treatment. Though sterilized, heat-treated sludges still provide a good medium for bacterial regrowth. Clements (1983) describes experience in Switzerland where pasteurization was used at approximately 70 plants to disinfect sludge before land application. A subsequent investigation conducted under governmental auspices showed that the majority of the pasteurized products were contaminated with pathogenic bacteria. The presence of the bacterial pathogens was attributed to contamination downstream with bacteria that grew rapidly, even in sludge that had been thoroughly digested before pasteurization. Since that time, most post-pasteurization operations have been abandoned. Current practice in Germany and Switzerland is to pre-pasteurize sludge before digestion or to use thermophilic aerobic digestion for agricultural applications that require minimal pathogen densities in the sludge. With sludge digested after pasteurization, bacteria do not rapidly grow to high and sustained levels when contamination occurs.

Sludge injected into the ground is removed from potential contact with humans, and its moisture is rapidly removed by the soil. Underground injection could be a suitable way to reduce vector attraction in pasteurized sludges if the sludge is injected very shortly after pasteurization. However, it is difficult to define the allowable time between pasteurization and injection. If a very fluid sludge becomes contaminated, the mixing caused by pumping or transport could promote rapid growth of bacterial contaminants to high densities.

Good housekeeping could reduce (but hardly eliminate) sources of contamination. Rather than specifying some time period, it seems more

reasonable to look for evidence of regrowth. Fecal indicators would very likely still be present in the pasteurized sludge and would almost certainly be among the contaminating organisms. If these organisms increased from their acceptable level of below 100/g solids to over 1,000/g VSS, this would indicate contamination that could pose a health concern. If densities are below 1,000/g VSS at the time of disposal, the likelihood of high densities of contaminating bacterial pathogens is considered unlikely.

Sludge cake is much less likely to become contaminated than liquid sludge because its drier nature limits mixing of any contamination into the entire sludge mass. The potential for contamination of sludge cake could be controlled by establishing a reasonable time limit between pasteurization and disposal; however, this might be difficult to establish. Therefore, the requirement that regrowth of indicator organisms be limited to 1,000/g VSS at the time of injection seems reasonable for protecting against regrowth in both liquid sludge and sludge cake injected underground. This is the approach taken in the regulations to ensure that substantial regrowth has not taken place in Class A sludges prior to underground injection.

In the 1979 "Criteria," heat treatment was considered a process to further reduce pathogens. In the present regulation, heat-treated sludge would need to either (1) be treated by a process to reduce vector attraction, or (2) be injected underground under the conditions stated above. This requirement applies to both heat-treated liquid sludge and dewatered sludge cake. It may be possible to establish that sludge cake produced from a heat-treated sludge, with a solids content above a certain percentage, would not attract vectors. Information supporting such a contention would have to be presented to EPA's Pathogen Equivalency Committee for a determination.

3.2.2.2 Vector Attraction Reduction (§503.53)

The potential for sludge to attract vectors must be reduced to break an important link in the disease cycle. Vectors can transmit pathogens from sludge, and they can contaminate sludges with pathogens. Therefore, even

sludges that have received Class A pathogen reduction treatment require reduction in vector attraction. The regulation lists five means to reduce vector attraction. These are discussed below.

Volatile Solids Reduction

If the sludge volatile solids content has been reduced 38% by anaerobic or aerobic biological treatment or chemical oxidation, it is presumed to be adequately reduced in vector attraction. This requirement, which is the same as was used in "Criteria," was drawn from the Water Pollution Control Federation Manual of Practice No. 8 (WPCF, 1967). The selection was largely judgmental but has been reinforced by 9 years of usage under the present regulation. Volatile solids reduction is calculated by a volatile solids balance around the digester or by the Van Kleek formula (Fisher, 1984).

The proposed regulation allows use of an alternative means to determine whether a 38% volatile solids reduction has been achieved. In many treatment plants, treated sludge is recycled back to the aerator for more treatment or back to the inlet of the digester to improve the fluidity of the incoming sludge. The sludge entering the digester has already been partially digested so it is extremely difficult to achieve an additional 38% volatile solids digestion.

Jeris et al. (1985) experimented with several sludges and attempted unsuccessfully to develop a single index that would characterize the stability of a sludge. They did demonstrate that most of their anaerobically digested sludges could be further digested to a modest degree, while a few of the sludges showed much more ability to digest further. This "ability to digest further" appears to be as close as we can come to an index of ability to putrefy further and attract vectors. The only problem is that 20-40 days are needed to complete the determination. The time requirement makes the method useless if a sludge must be immediately evaluated, but is no obstacle to evaluating an operating process. The test must simply be started 20-40 days before the result is needed.

Jeris et al.'s data showed the following additional percent volatile solids reduction after 40 days of additional digestion for six sludges: 9, 10, 13, 22, 36, and 38. The three sludges with the lowest volatile solids (VS) reduction also showed low volatile acid concentrations before the additional digestion period commenced. Because the percent VS versus time curves had essentially flattened out at 30 days, a VS reduction of 15% or less on additional batch digestion for 30 days was selected as adequate evidence of satisfactory vector attraction reduction. This reduction is stated to be equivalent to the aforementioned 38% volatile solids based on volatile solids entering and leaving the digester.

It is expected that a procedure for conducting this VS reduction test will be described in forthcoming EPA guidance. Jeris et al. (1985) used an 18-L digester with continuous mixing and gas release measurement. Because only volatile solids concentration would need to be measured, a smaller digester (e.g., 4-L) with no gas collection and intermittent stirring (once per shift) would be adequate. In the interim between proposed and final issuance of regulations, additional information should be obtained that supports this approach.

Specific Oxygen Uptake Rates (SOUR)

If a sludge has been treated aerobically to the point at which the biological organisms present are consuming very little oxygen, the value of the sludge as a food source for microorganisms is evidently very low. The likelihood that such a sludge will attract vectors when applied to the land surface or injected shallowly into the ground is likewise low. Eikum and Paulsrud (1977) have shown that both the odor index of aerobically digested sludges and the oxygen uptake level decline at about the same rate with increasing nominal residence time in a continuous flow (fed once a day) digester. The relationship between odor intensity and oxygen uptake rate is approximately in direct proportion. Eikum and Paulsrud's results indicate that at 20°C, an oxygen uptake rate of 1.5 g/hr/g VSS or less indicates a

well-stabilized sludge. The oxygen uptake rate depends on the temperature of digestion. Within a range of ± 5°C, the oxygen uptake rate obtained at another temperature can be converted to the uptake rate of 20°C by the following relationship:

$$SOUR\ (20°C) = SOUR\ (t°C) \times 1.10^{(20-t)}$$

The oxygen uptake rate depends on the conditions of the test and, to some degree, on the nature of the original sludge before aerobic treatment. Similarly the temperature correction also depends on the nature of the sludge. EPA's forthcoming guidance will provide information on test procedures and sludge-dependent factors.

Alkali Addition

Vector attraction can be reduced by alkali addition; however, the reduction is not permanent. Alkali addition does not significantly change the nature of the substances in the sludge but instead causes stasis in biological activity. If the pH should drop, the surviving bacterial spores would become biologically active, and the sludge would putrefy and attract vectors. The regulation provides target conditions that, if met, will ensure that the sludge can be stored briefly at the treatment plant, transported, and applied to the soil without the pH falling to a point where putrefaction occurs and vectors are attracted.

Noland et al. (1978) have shown that with addition of quicklime or slaked lime, sludge pH remains high for extended periods. His Figure 9 shows that for a sludge raised to pH 12.5, pH did not fall to below 12 for 25 days. One reason the pH stays high for such a long period is that a substantial portion of the lime is still not dissolved; this excess lime dissolves as the pH starts to drop below 12.5. Other alkalis, such as cement kiln dust or wood ash, are more soluble, so at pH 12 or above little undissolved alkali may be present to help maintain the pH as it starts to fall. The requirement for pH to exceed 11.5 for 24 hours after lime addition is to ensure that it will be

high long enough to dispose of the sludge even if a large proportion of the alkali is soluble. Obviously, collection of additional data using soluble alkalies to raise pH will be helpful in substantiating these time-pH requirements.

Moisture Reduction

Drying sludge to near total dryness causes a stasis in biological activity. Sludge products such as Milorganite (Milwaukee's heat-dried waste-activated sludge) contain less than 10% moisture. They exhibit no biological activity when kept dry and resist recontamination unless water is added. Yeager and Ward's (1981) data show that bacterial densities in sterilized raw sludge inoculated with several bacterial species declined rapidly when the solids contents were over 75%, indicating diminished bacterial activity. Thus, it can be concluded that significant biological activity will not occur if sludge is maintained above 75% solids. However, the nature of the sludge and the manner in which it is handled can influence the degree of vector attraction. Most air- or heat-dried sludges do not contain raw sludge from a primary clarifier. Raw sludge from a primary clarifier could contain undegraded or partially degraded food fragments, including rancid fats. It is therefore prudent not to use the 75% dryness level as a measure of reduced vector attractiveness in sludges that contain raw sludge from primary clarifiers. Heat drying of such sludges to a much higher solids content will further limit biological activity and will strip off or decompose volatile compounds that attract vectors. Permit conditions may allow reduction in vector attraction to be demonstrated by such means if supported by experimental findings.

The conditions of handling dried sludge before disposal can create or prevent vector attraction in dried sludge. For example, sludge that was air-dried to 75% solids on a sand bed and stored in piles under a roof could become a problem in periods of cool weather with high humidity (e.g., during a prolonged rainy period or a change of seasons). The outer surface of the sludge would equilibrate to a lower solids content and could attract vectors.

This possibility can be avoided by devising appropriate permit conditions and is not sufficient justification for either rejecting drying as a method to reduce vector attraction or including a requirement to store the dried sludge in climate-controlled storage or in bags.

Subsurface Injection

When sludge is injected under the soil surface and does not leak substantially to the surface, vectors no longer have easy access to the sludge, and the odors that might attract vectors are reduced. The sludge intimately contacts the soil and, in ordinary circumstances, the soil extracts water from the sludge and dewaters it. The method could fail if loading rates (mg dry solids basis/hectare) were unusually high and the soil was saturated with water. When sludge is applied at agronomic rates to soils that do not have a high moisture content, problems are not expected. Permit conditions should specify maximum liquid loading rates and should specify that sludge not be injected into moist soil.

3.2.3 Class B Requirements

Class B requirements are based on the observation that wastewater sludges produced by conventional treatment (including anaerobic digestion) and used in a careful fashion on farmland pose a minimal disease risk. Class B requirements specify that sludge be treated to produce log average reductions in pathogenic bacteria and animal viruses equivalent to the reductions achieved by this conventional treatment. They also require reduction of vector attraction, and establish controls over site access, crops grown and harvested, and animals grazed. Together, these requirements reduce the disease risk to minimal levels.

Class B does not require reduction of protozoan cysts or helminth eggs. Protozoan cysts are believed to be greatly reduced in numbers by sludge processing and are relatively susceptible to adverse environmental exposure.

Even if survival were substantial, they would be effectively controlled by the access and use restrictions. Helminth eggs are hardly reduced at all by processing, and densities decline slowly in the environment. The requirements forbidding growth of certain crops for 18 months and restricting site access for 12 months are designed to protect the public against possible ingestion of helminth eggs.

3.2.3.1 Pathogen Reduction (§503.52)

Class B pathogen reduction requires that the logarithm (base 10) of the average density of pathogenic bacteria per unit mass of volatile suspended solids in the processed sludge is at least 2.0 lower than the logarithm (base 10) of the average density of pathogenic bacteria per unit mass of suspended solids in the influent to the treatment works. For viruses, the difference in these two densities must be 2.0 or greater.

The use of the difference in pathogen log densities in suspended solids in influent wastewater and suspended solids in processed sludge is a new development. In "Criteria," the objective of the processes to significantly reduce pathogens was to ensure that all sludges received at least a certain minimum degree of treatment. Farrell et al. (in press) and Lee et al. (in press) established that this approach is inequitable for some treatment plants because the sludge from certain wastewater processes is lower in fecal indicators and bacterial pathogens than other processes. The implication of their work is that the wastewater treatment process itself is part of the sludge treatment. One is then forced to look upstream before wastewater treatment starts to find a measurement against which residual pathogen densities in sludge can be compared to measure performance.

Two upstream measurements have been selected as indices of pathogen burden: the pathogen densities and the bacterial fecal indicator densities in the entering wastewater as related to the mass of the volatile suspended solids in the wastewater. The volatile suspended solids was selected as the "solids" stream of concern because it contains the great bulk of the pathogens

(including the viruses that are adsorbed on solids). The nonvolatile fraction of sludge (dirt, grit) mechanically carries along pathogens, but the pathogens are part of the volatile solids fraction of the sludge solids.

Selection of the pathogen densities as an index needs no explanation. As for the fecal indicator densities, they are direct measures of fecal contamination provided the wastewater has not yet been subjected to treatment adverse to bacterial survival, which is a reasonable assumption at the treatment plant inlet. Because fecal matter is directly related to pathogen burden (at least in the long term), fecal indicators at the plant inlet will be related to pathogen burden also, and their densities (mass basis) will serve as an index of pathogen burden in the sludge.

For the purposes of evaluating Class B (and Class C) treatment to reduce pathogens, wastewater treatment and sludge treatment are considered as steps taken to reduce the pathogen density (no./g VSS) in the incoming wastewater solids. For those processes for which fecal indicators fall in a manner that correlates uniformly with the fall in pathogen content, the fall in fecal indicator densities (mass basis) can be used to indicate the fall in pathogen densities.

What is needed now is information on typical wastewater and sludge treatment processes that shows that fecal indicators, bacterial pathogens, and animal viruses all fall in about the same fashion. Information is available that shows that this is true for aerobic treatment and mesophilic anaerobic digestion. Martin (in press) obtained data on the relative declines in fecal indicators and animal viruses at temperatures from 8-40°C. In the temperature range of 15-31°C, the reductions did not show marked trends with temperature. Ratios of log reductions for fecal indicators relative to log reductions for viruses were calculated for seven temperatures in this temperature range. Average ratios and standard error of the mean are shown in Table 3-2, and are compared with Farrell et al.'s (1985) data for anaerobic digestion at 35°C.

The differences are not great. The agreement is particularly good for fecal streptococci. It is reasonable then to conclude that for aerobic and anaerobic processes in the commonly used temperature ranges, a decline in

fecal indicator densities can be used to indicate declines in viruses for both cases. Because of the scarcity of data (there were insufficient numbers of salmonellae in Martin's influent for him to observe the fate of this pathogen), it is necessary to assume that the declines in salmonellae relative to the indicators would be similar for both types of processes.

For processes conducted at temperatures higher than 35°C, available information (Farrell et al., in press; Martin, in press; Berg and Berman, 1980) indicates that viruses fall faster than indicators. However, this issue does not require discussion because bacterial and viral reductions are much greater than two logs at thermophilic temperatures.

The situation for chemical treatment of sludge by lime or chlorine is similar to that for biological treatment in the thermophilic range. Under these treatments, bacteria and viruses fall to a much greater extent than the minimum requirement for Class B treatment. For lime treatment, results by Counts and Shuckrow (1975) and Strauch (1982) show that bacteria and viruses are greatly reduced at pHs exceeding 12. When wastewater is treated by chlorine to a pH near 7, the free chlorine inactivates polio virus and E. coli to a similar extent (Table 5-11 in EPA, 1986). In sludge treatment the bulk of the chlorine would be converted to chloramines. Reduction in viruses would occur but more slowly. Adequate contact time with the sludge would be necessary. Typically, contact times of fewer than 30 minutes provide adequate virus destruction.

For those processes for which the fall in indicators correlates with the fall in pathogenic bacteria and viruses, the proposed regulation sets a criterion for pathogen reduction based on the absolute densities of fecal indicators in treated sludge for certain processes. This criterion requires that the average log fecal coliform densities (no./g VSS) shall be less than 6.0 and the average log fecal streptococci densities (no./g VSS) shall be less than 6.0 in the processed sludge. The rationale for this is as follows. Until now, reductions in pathogen densities have been estimated by correlating them to reduction in indicator densities. Absolute densities of the fecal indicators can be used as a criterion because the densities of the indicators in entering wastewater are surprisingly similar for different wastewater

treatment plants; as a result, indicator densities after adequate treatment to reduce pathogens are also expected to be similar. Farrell et al. (in press) found that the ranges in log densities for total coliforms, fecal coliforms, and fecal streptococci were 0.55, 0.43, and 0.43, respectively, for four NP/LSA (no primary/long sludge age) plants and one conventional plant. Densities in this study were on a total solids basis. It is expected that Olivieri and Sarai's results (1988, in press) will confirm this observation, when their investigation is completed.

For unique processes that might not adequately destroy viruses or pathogenic bacteria, it will be necessary to either (1) collect information to show that fecal indicators can be used as indicators of bacteria and virus destruction, or (2) measure either pathogenic bacteria or animal virus densities (whichever is the least sensitive to the process) to indicate performance.

3.2.3.2 Vector Attraction Reduction (§503.53)

All vector attraction processes for Class B are the same as for Class A, except, for Class B, the vector attraction process may precede, follow, or occur simultaneously with pathogen reduction. The Class A requirement that the vector attraction reduction process cannot precede the pathogen reduction process is unnecessary for Class B because regrowth of bacterial pathogens is unlikely in Class B sludges, because some competitor bacteria remain in the sludge following treatment. For the same reason, no requirement exists to determine fecal indicator densities to ensure that regrowth has not occurred when vector attraction is reduced by underground injection.

3.2.3.3 Access and Use Restrictions (§503.52)

Class B requirements reduce pathogenic bacteria and animal viruses, but some of these organisms still survive in the sludge. Protozoan cysts, although probably the most susceptible pathogen to wastewater and sludge

treatment, may also be present. Helminth eggs, if present in the untreated wastewater, are very likely to be present because they are the least affected of the pathogen types by wastewater and sludge treatment. Access and use restrictions have been imposed for Class B sludges that either limit exposure or provide time for attenuation of pathogens so that the risk of disease is minimal.

Food crops whose harvested parts are above the ground and touch the sludge or soil-sludge mixture cannot be grown for 18 months after application of a Class B sludge. Food crops whose harvested parts are above the ground and do not touch the sludge may be grown at any time. The 18 months provides time for attenuation of pathogens -- particularly helminth eggs. Kowal's (1985) review points out that helminth eggs are degraded by exposure to sunlight and desiccation but survive for years when protected by the soil. The long time period allows time for sun and desiccation to inactivate the helminth eggs, which are the pathogen type most resistant to environmental stress.

The proposed regulation requires that food crops whose harvested parts are below the surface shall not be grown for 5 years after land application of Class B sludge, or 18 months if it is demonstrated at that time that there are no viable helminth eggs in the soil. Research has shown that helminth eggs below the soil surface survive in some soils for periods well in excess of 18 months (Jakubowski, 1988). After 5 years their survival is expected to be low. Some sludges are initially low in helminth eggs. Initial low densities coupled with the declines that occur after 18 months may produce trivial densities in soil. It is reasonable to allow use of the soil for root crops after 18 months if helminth eggs are demonstrated to be absent. Measurement of low densities of helminth eggs in soil requires proper methodology and training. A demonstration that helminth eggs are absent will be accepted only if the ability to recover small numbers of helminths in soil is also demonstrated.

Any food crops grown on agricultural land where Class B sludge has been applied shall not be harvested for 30 days after sludge application. This protection is needed because animals and humans may contact these harvested crops very soon after harvesting. A period of exposure to environmental

conditions before harvesting allows wind action and rainfall to reduce the amount of sludge adhering to the crops and to attenuate pathogens. Exposure of pathogens on the plant surface is especially severe because the sludge layers are thin and desiccate quickly. As noted earlier, viruses on low-growing vegetables have been shown to decline to low values in less than 2 weeks (Larkin et al., 1976). Consequently, prevention of harvesting for 1 month is considered sufficiently protective.

The proposed regulation requires that animals be prevented from grazing for 30 days after sludge is applied to the land. This requirement is primarily designed to protect human health. Animals can physically carry sludge off the site where humans may inadvertently come in contact with it. Prevention of any grazing for 1 month after sludge use to allow attenuation of pathogens and removal of sludge from plant surfaces by rain and wind is appropriate and is considered to be sufficiently protective. The requirement also protects animals against bacterial or viral diseases, such as salmonellosis, which can be transmitted to humans; however, it is less protective against helminths such as Taenia saginata (beef tapeworm). These organisms are somewhat attenuated within a month, and agricultural inspection of meat for cysticercosis reduces the risk of creating a cycle of infestation.

The proposed regulations require that public access to a site be prevented for 12 months after application of Class B sludge. This restriction does not apply to farm owners and agricultural workers who are aware of the presence of sludge; it does apply to the uninformed public. The 12-month period is fully protective against viruses, bacteria, and helminths. The restriction on access is shorter than the restriction against growing food crops because the exposure to helminths by walking or sitting on the ground is assumed to be less than exposure by ingesting food crops grown on soil containing sludge.

3.2.4 Class C Requirements

3.2.4.1 Pathogen Reduction (§503.52)

Class C requirements stem from the observation by Farrell et al. (in press) and Lee et al. (in press) that sludge produced by "no primary/long sludge age" (NP/LSA) plants (i.e., by wastewater treatment plants that do not use primary clarification but expose wastewater and sludge to aerobic conditions for long periods) is more reduced in salmonellae and fecal indicator densities than untreated sludge from a conventional treatment plant that utilizes primary clarification and the conventional activated sludge process. It is well known that NP/LSA sludges are better stabilized than the typical mixed primary and waste-activated sludge from a conventional plant. In the past, NP/LSA plants have frequently had difficulty meeting the volatile solids reduction for aerobic digestion specified in "Criteria" because they already had lost much of their volatile solids in the wastewater treatment step. The "Criteria" treatment of these sludges was inequitable. Class C acknowledges that these sludges are nearly but not quite as reduced in pathogens as sludges that have received Class B treatment.

Estimation of the pathogen reduction across NP/LSA plants is approximate because almost no experimental work has been done relating pathogens and indicator densities (mass basis) in inlet wastewater solids to their densities (mass basis) in the waste sludge at these plants. The pathogen reductions of 1.5 logs (base 10) shown in the proposed regulation are estimates based on reductions in densities of fecal indicators achieved by processing.

Table 3-3 shows densities of indicator organisms in the processed sludge from several conventional treatment plants that anaerobically digest their sludge and from several NP/LSA plants. The data show suggested ranges and standards for fecal indicators for these sludges. Considering only fecal coliforms and fecal streptococci, the NP/LSA sludges show densities that averaged about 0.5 logs higher than for the conventional sludges. Using the estimates of the ratio of log viral to indicator reductions presented in Table 3-2, log viral reductions are estimated to be approximately 0.5 log poorer for

NP/LSA processes. For bacteria, the NP/LSA processes showed an overall log reduction in fecal streptococci of about 1.4 and a Salmonella spp. reduction of 1.2 (Farrell et al., in press; Lee et al., in press). For bacteria, the 0.5 less reduction in fecal indicators will mean approximately 0.4 log less reduction in pathogenic bacteria.

On this basis, the proposed regulation states that average log fecal coliform densities (no./g VSS) shall be less than 6.3, and average log fecal streptococci shall be less than 6.7. As noted in Section 3.2.3, it is possible to use absolute densities (as opposed to reductions in densities) as standards because densities of fecal indicators in the incoming wastewater (no./g VSS) are nearly the same at wastewater treatment plants.

The fact that the proposed 1.5-log reduction in pathogenic bacterial and viral densities for NP/LSA plants has been estimated is recognized. For the most part, this creates no difficulties because most facilities will be able to use absolute fecal indicator densities of the treated sludge to demonstrate conformance with regulations. The primary objective is to show that the intent of the regulation is to control pathogen densities and not indicator organism densities.

3.2.4.2 Vector Attraction Reduction (§503.53)

The Class C vector attraction reduction requirements are exactly the same as the Class B requirements. No further discussion is needed.

3.2.4.3 Access and Use Restrictions (§503.52)

Class C access and use restrictions are similar to but more rigorous than Class B requirements. The 1-month time restrictions in the Class B requirements, which are designed to protect primarily against risks from pathogenic bacteria and viruses, are increased for Class C requirements. The 18-month and 5-year time restrictions in the Class B requirements are designed

to protect against risk from helminth eggs. Sludge processing used to achieve Type B and C pathogen reduction requirements will have a similar slight effect on helminth eggs survival; consequently, the time periods chosen to protect human health from helminth risk associated with Type B sludges will also be protective for Type C sludges.

The proposed regulation requires that feed crops whose harvested parts touch the sludge and are above ground cannot be grown for 18 months after application of Class C sludge. Feed crops whose harvested parts are below the surface shall not be grown for 5 years after application of Class C sludge to the land, or 18 months if it is demonstrated that no viable helminth eggs can be found in the soil. These requirements are the same as for Class B.

Any food crops grown on agricultural land where Class C sludge has been applied shall not be harvested for 2 months after sludge has been applied. This is an increase of 1 month over Class B requirements. Additional time is required for attenuation because bacterial and viral pathogen levels are slightly higher in Class C sludges than Class B sludges.

Animals must be prevented from grazing for 2 months after Class C sludge is applied to land. This is an increase of 1 month over Class B requirements. Additional time is needed for attenuation of viruses and pathogenic bacteria because the initial pathogenic bacterial and viral content is higher in Class C sludges.

The Class C access restrictions are more rigorous than the Class B restrictions. Both classes require control of site access for 12 months in both cases; however, for Class C, only agricultural workers are allowed access to the site during the 12 months. For example, members of farm families who were not directly involved in crop production activities could visit fields where Class B sludge had been applied, but would not be allowed in areas where Class C sludge had been applied. Only workers actively managing crops would be allowed access to an area where Class C sludge had been applied.

3.2.5 Septage

The proposed regulation defines septage as sewage sludge, so all the requirements, including those concerning control of disease risks, apply to septage. Thus the regulation requires that septage cannot be disposed to the land surface unless it meets Class A, B, or C requirements. This is a departure from "Criteria," which allowed septage to be utilized on the land without any treatment under a slightly different set of restrictions than those for sewage sludge.

Septage pumped from a septic tank is ordinarily an extremely noxious substance. However, if the septic tank has experienced little use, particularly recent use, the septage could be low in pathogens and fecal indicators and well stabilized. Except for the temporary burst of noxious odor when such a material is applied to the soil, it might pose few problems and little disease or vector attraction threat. Finding practical ways to demonstrate that the typical 1,000-gallon tank truck load of septage poses little disease risk is difficult. Almost any sampling and analysis scheme would be more expensive than paying to have the sludge processed by a wastewater treatment plant or a special facility for treating septage. The regulation will probably move septage disposal in this direction.

Some question remains whether allowing septage to be applied after meeting Class B or C requirements is wise. The nature of infection is that a person is free of pathogens most of the time and only occasionally sheds pathogens in feces. In the treatment of a community's wastes, an averaging effect comes into play. Most of the time the sludge has low levels of pathogens that must be lowered still more to be sure disposal is safe. On the other hand, most septic tanks serve a single household. Consequently, most septage loads are not contaminated, but occasionally, a load will be very "hot" with pathogens. For example, it is not uncommon for several family members to be carriers of salmonellae for several weeks after an infection in the family, or one or two people in a family may have an Ascaris infestation. The methods used to meet Type B and C requirements reduce pathogens by factors of 10 to 100. Ordinarily, this provides ample protection, but it might not if densities are

a thousand times higher than the ordinary maximum values encountered in an untreated sludge from a wastewater treatment plant. Considered in this light, septage disposal should be moved toward community treatment centers or wastewater treatment plants.

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